Can quantum nonlocality be explained using (complex) Maxwell equations?

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Abstract

Quantum nonlocality belongs to one puzzling feature of quantum mechanics, which some people think as unexplained using classical theories. But there seems a possibility to explain quantum nonlocality using Maxwell equations or complex Minkowski approach. Therefore it seems worth to discuss this issue.

Introduction

This file is summary of discussion in researchgate.net about possible explanation of quantum nonlocality using (complex) Maxwell equations.

Quantum nonlocality belongs to one puzzling feature of quantum mechanics, which some people think as unexplained using classical theories. But there seems a possibility to explain quantum nonlocality using Maxwell equations or complex Minkowski approach.

See for instance, Wheeler-Feynman absorber theory, which is an interpretation of electrodynamics derived from the assumption that the solutions of the electromagnetic field equations must be invariant under time-reversal symmetry, as are the field equations themselves. Ref. http://en.wikipedia.org/wiki/Wheeler%E2%80%93Feynman_absorber_theory. This theory is related to Transactional Interpretation of Quantum Mechanics suggested by John G. Cramer, see http://en.wikipedia.org/wiki/Transactional_interpretation.

Another approach is proposed by Amoroso and Rauscher, who suggest complex Minkowski theory to explain nonlocality (Ref. http://vixra.org/pdf/1305.0055v1.pdf). But they derive complex Maxwell equations elsewhere (Ref. http://vixra.org/pdf/1305.0099v1.pdf). Perhaps the role of complex geometry to explain nonlocality cannot be overemphasized, as Hadamard once wrote: the shortest path between two truths in real domain passes through the complex domain. (url: http://homepage.math.uiowa.edu/~jorgen/hadamardquotesource.html)

Answers:

[1] **Manuel Calixto**

If by "quantum non-locality" you mean ``entanglement", I do not think that, in principle, complex Minkowski space has any role in that.

Complex Minkowski space could play a fundamental role at short distances, when quantum mechanics and general relativity merge. In fact, Born's Reciprocity Principle, which proposes an invariance of the laws of nature under the interchange of four position and four momenta, implies the existence of a minimal (Planck) length and, therefore, a ``granular" structure of space-time (see e.g.

http://arxiv.org/abs/1006.5958 for a discussion and references). You could also see here a kind of ``non-locality''.

[2] **Stam Nicolis**
Maxwell's equations are *classical* equations-so they cannot describe quantum phenomena, in general and entanglement in particular-they don't describe photons, but (classical) electromagnetic waves.

Minkowski space(time) is, also, classical.

If you want to describe *quantum* effects, you need to introduce quantities that depend on Planck's constant and look at the consequences this leads to.

It's essential to keep in mind that quantum mechanics is, usually, expressed in *phase space*, not *spacetime* and a lot of confusion results from mixing the two. Quantum mechanics in spacetime is described through the path integral formalism of Dirac and Feynman. But here all quantities are *classical* and quantum effects are described in a more indirect fashion.

[3] **Victor Christianto**
Dear Manuel and Stam, thank you for your answers. Yes quantum effect cannot be derived from classical equations, nonetheless there is known correspondence at least on theory between the two. For instance, Ward and Volkmer show how Schrodinger equation can be derived from classical wave equation (see http://arxiv.org/pdf/physics/0610121.pdf). Of course there is missing planck constant in classical wave equation. Furthermore, others are able to find connection between Schrodinger equation and Newton law (such as Edward Nelson). But i am not sure if there is nonlocality in classical wave equation.

[4] **Daniel Baldomir**
Dear Victor,
You ask on quantum non local correspondence with Maxell equations and these are at least two very different aspects.
Classical Electrodynamics is a local theory if we think that it cannot take into account the topological terms due to have the Maxwells equations written as local fields. In fact they are obtained from an action which only use the Lorentz scalar invariant associated to the fields and it forgets the pseudoscalar invariant E.B which is the one that could give topological non local information.
On the other hand Classical Electrodynamics can be quantized as it was done in QED quite sucessfully. And the introduction of topology in Electrodynamics is made through the Chern numbers (or other topological number) associted to the fields and in fact to invariants as the Lorentz invariant that was mentioned previously. Mathematically the best form to glue the local and local properties of Electrodynamics is to represent it in a principal fiber bundle with the characteristic classes associated. Finally there is not a unique correspondence between a local theory and a global or non local one: they depend strongly on the boundary conditions of the functional space of their solutions. This is one of the great problems for trying to quantize the Einstein's gravity.

[5] **Stam Nicolis**
There does exist a transform from phase space to space-time, the Wigner transform. Of course it's not covariant since quantum mechanics is non-relativistic, but that's beside the point. This is an operator-valued transform in one-particle quantum mechanics and doesn't have anything to do with Maxwell's equations, however.

By definition, quantum effects are functions of Planck's constant. Schrödinger's equation describes quantum effects, *because* it contains Planck's constant. The quantity of interest, the wave function is a function on phase space, NOT space-time, whatever people may claim. To pass from phase space to space-time one either uses the Wigner transform of the wave function or the path integral formalism-Feynman's paper of 1948 in Rev. Mod. Phys. is the reference on the subject.

In the path integral formalism, Planck's constant enters in the phase factor, that weighs each path.

In Nelson's formalism, Planck's constant enters in the variance of the noise term.

It's a new constant, unrelated to anything else. Since it's dimensionful, we can choose *units* such that its numerical value, in those units, is equal to 1-but that doesn't mean it has disappeared from the physical consequences of the equations.

What's interesting is that one can obtain *classical* effects as limiting cases of *quantum* effects.

[6] **Stam Nicolis**
Your welcome. Another point to keep in mind is that the generalization of the Wigner transform to systems of an arbitrary number of particles, i.e. a field theory, is hard to get. The way to describe therefore field theories, in a way consistent with their symmetries, classically and quantum mechanically, is the path integral formalism. The lattice regularization then leads to a formulation that is, also, mathematically well-defined. Here, however, most explicit calculations require numerical methods, but can be checked by mathematical analysis.

Of course all this holds for *fixed* spacetime background. How to describe quantum effects, when the space-time can fluctuate, too, is, still, an open issue.

[7] **Spiros Koutandos**
Dr Arbab Arbab from Sudan has published a paper on the matter. You can find him (and the article) at www.academia.edu . By the way I publish on the hidden variables of quantum mechanics at www.gsjournal.net or you can read my articles at researchgate

[8] **Daniel Baldomir**
I think that the question was very clear, although complex or impossible to answer as it stands: Can quantum nonlocality be explained using (complex) Maxwell equations?

Obviously, no; if we follow it literally. But we can extend a little bit the response for distinguishing quantum and nonlocality from classical theories as the Maxwell's Electrodynamics. I have attached a paper devoted to explain how there are not univoque answer when you pass from a classical to quantum theory (best example and no resolved: Einsten's gravity).

Let me to tell you that the Hamiltonian formalism in Electrodynamics is not allowed univocally too because there are not a Legendre transformation independent of the gauge and also the electric field doesn't depends of a time derivative of the scalar potential. See for instance:

D.Baldomir and P.Hammond, Geometry of Electromagnetic Systems, Clarendon Press, 1996.

I attach you another reference more for trying to explain the difficulties and where they are for both concepts: quantum and nonlocality.

[9] **Victor Christianto**
@Daniel. Thank you for your comments, yes I agree with you that classical electrodynamics cannot describe quantum phenomena, but as Gersten and also Raymer and Smith have shown, it is possible to derive Maxwell wave function for photon. See for instance, http://arxiv.org/pdf/quant-ph/0604169.pdf. So it seems there can be correspondence at least in theory to describe quantum mechanics in terms of electrodynamics.
Furthermore, i read elsewhere a quote by a physicist who says that up to now there are two theories to describe electron, first using Maxwell theory, and second using quantum mechanics. Since experiment shows that electron can behave like particle or wave, then it seems that there should be coherent picture between quantum mechanics and classical electrodynamics. If Maxwell theory cannot explain quantum mechanics, does it mean that we should better use nonlinear electrodynamics? Best wishes

[10] **Daniel Baldomir**
Maxwell's electrodynamics doesn't know what is an electron and I do not know what is non linear electrodynamics. In quantum mechanics the electron may be described by a de Broglie matter wave which is very far of classical electrodynamics.

The Schrödinger equation, although we always speak about the wave function, it is not a wave equation at all. Meanwhile the photons or the electromagnetic waves follow a real wave equation equivalent to Maxwell's equations.

In QED you can combine them but separating clearly one of the other.

[11] **Daniel Baldomir**
The paper that you recommend is clearly wrong, besides it doesn't prove anything and only write analogies for equations, what call Maxwell's equations in the flow of fig.1 are nothing more than Faraday and Ampere when the density of current is zero. Notice that in this case even the fields are not determined following the Helmholtz theorem.

[12] **Victor Christianto**
Thank you, Daniel, for your answer. Yes we can use De Broglie matter wave to describe electron, but then we have a wave function. But the Schrodinger wave function only has probabilistic meaning. You are an expert, i hope you don,t mind if i ask one more question: is there electromagnetic picture of the quantum wave function? Thanks

[13] **Daniel Baldomir**
No, the wave function even is without physical meaning. What has meaning is its square following Max Born and gives the density of probability only!

[14] **Victor Christianto**
Ok, i understand what you mean that the wave function does not have a physical meaning. Then if we follow your argument that electron can be described by a wave function, but the wave function only has probabilistic interpretation, then it would mean that the electron itself is not a physical entity. Am i right? I think that is part of the reason why Einstein-Podolski-Rosen wrote in 1935 that the quantum mechanics is incomplete. Best wishes

[15] **Daniel Baldomir**
The electron itself is not described by the wave function, what describes the wave funcion as an eigenfunction of the Hamiltonian y the eigenenergy or its momentum. Thus it is posible to know a wave length or a frequency of a real wave movement. This is the de Broglie wave of matter, broadly speaking.

In any case I recommend you to read a basic quantum mechanical textbook as:
Claude Cohen-Tannoudji, Bernard Diu, Frank Lalöe, Quantum Mechanics,
Vol. I and II.
That you can find in internet and it is very good and exhaustive, from my humble point of view.

[16] **Victor Christianto**
Thank you, Daniel, for the reference, i will try to find it. Btw, there is new paper by Blackledge and Babajanov (2013) whihch discuss wave function solution based on correspondence between Helmholz and Schrodinger equations. See http://arrow.dit.ie/cgi/viewcontent.cgi?article=1080&context=engscheleart2&sei-redir=1&referer=http%3A%2F%2Fwww.google.com%2Furl%3Fsa%3Dt%26rct%3Dj%26q%3Dhelmholtz%2520schrodinger%2520correspondence%2520greenleaf%26source%3Dweb%26cd%3D3%26ved%3D0CDAQFjAC%26url%3Dhttp%253A%252F%252Farrow.dit.ie%252Fcgi%252Fviewcontent.cgi%253Farticle%253D1080%2526context%253Dengscheleart2%26ei%3DrvYQU_bkK4yCrgff5oGgBA%26usg%3DAFQjCNHTmlZruy9zTnrPZowKp5r1g-6rjA#search=%22helmholtz%20schrodinger%20correspondence%20greenleaf%22.

Another paper discussing Helmholtz equation is written by Greenleaf et al., but they only use it to solve invisibility cloaking problem. Best wishes

Concluding remarks
From this discussion, it seems clear that it is not possible to explain quantum non-locality using Maxwell equations or their extension to complex Minkowski. However, I got an impression that it is possible to find an electrodynamics description of electron, though this question remains impossible to answer in quantum mechanics because the wave function has no physical meaning.

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